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THE PROBLEM OF THE SOARING BIRDS.

BY I. LANCASTER.

SAYS Darwin, in the naturalist's voyage around the world: "When the condors are wheeling in a flock round and round any spot, their flight is beautiful. Except when rising from the ground, I do not recollect ever having seen one of these birds flap its wings. Near Lima I watched several for nearly half an hour, without once taking off my eyes: they moved in large curves, sweeping in circles, descending and ascending without giving a single flap. As they glided close over my head, I intently watched from an oblique position the outlines of the separate and great terminal feathers of each wing; and these separate feathers, if there had been the least vibratory movement, would have appeared as if blended together; but they were seen distinct against the blue sky. The head and neck were moved frequently, and apparently with force; and the extended wings seemed to form the fulcrum on which the movements of the neck, body, and tail acted. If the bird wished to descend, the wings were for a moment collapsed; and when again expanded with an altered inclination, the momentum gained by the rapid descent seemed to urge the bird upwards with the even and steady movement of a paper kite. In the case of any bird *soaring*, its motion must be sufficiently rapid so that the action of the inclined surface of its body on the atmosphere may counterbalance its gravity. The force to keep up the momentum of a body moving in a horizontal plane in the air (in which there is so little friction) cannot be great, and this force is all that is wanted. The movement of the neck and body of the condor, we must suppose, is sufficient for this. However this may be, it is truly wonderful and beautiful to see so great a bird, hour after hour, without any apparent exertion, wheeling and gliding over mountain and river."

The above remarkable words for many years have served to sustain my interest in the endeavor to substitute the actual for his provisional solution of soaring flight.

I presented in this magazine certain papers of a suggestive character, the results of much observation and experiment, in the hope of directing attention to curious facts, not recognized, bearing upon this subject. Three years ago I moved to my present location, Egeria, Colorado, where, during the past eighteen months, I have done the principal work necessary for this undertaking.

I consider myself successful in obtaining important results. In this paper I propose dealing with an experiment so obviously simple, as it now stands, that I am dazed to think of the labor that has been expended upon it. This device, in wind, really exhibits the entire soaring case in a very concise way, so far as its fundamental principles are concerned; but I give briefly the same experiment in calm air, as supplementary. The first form of the experiment can be tried by any one with a fair amount of constructive ability, and it cuts an awful chasm through the teachings of the mechanical schools on atmospheric resistance, and unerringly points to practical air navigation.

A rough-board platform, about twelve feet square, with a post and cross-beam fixed upon it, the whole being capable of horizontal rotation to present the plane to the wind from whatever direction it might blow, is the framework.

The plane should be a flat pyramid,—5x5 feet square is a good size on the base, and two inches high. The edges of such shape, being sharp, give the effect of a true plane without thickness. The whole should be finished smooth, similar to the top of an ordinary piano. Perfectly seasoned white pine or red cedar is an excellent material to use, glueing thin strips together in the rough, and dressing to shape.

To one edge of the plane two fine steel wires are fastened, which are suspended from two ordinary spring balances, fixed by their rings to the cross-beam of the platform. When thus suspended the plane will sway freely too and fro, like a child's swing, the flat side being in a vertical position when at rest.

To the apex at the back of the plane is fixed another wire provided with another spring balance, the ring of which is fastened to the rear part of the cross-beam, when the plane is drawn backward to any desired angle of obliquity with the horizon. This wire must in all cases be kept perpendicular, and the other two parallel to the plane.

It is obvious that the plane can be pulled backwards through all degrees of the quadrant, and suspended at any position by the wires and balances in a state of rest. While the plane hangs vertically all its weight will be on the parallel wires, half on each. As it is pulled to the rear less and less weight will be on the parallel wires, and more and more on the normal wire, until at a horizontal position, 90° from the starting point, all weight will be on the normal wire, and none on the parallel.

If we assume the soaring inclination of a bird to be 5° from horizontal, and pull the plane back to that angle, the normal scale will mark twenty-seven pounds and the parallel one pound each, small fractions of weight being neglected. If an angle of 45° be used, the normal scale will mark about nineteen pounds and the two others 9½ pounds each.

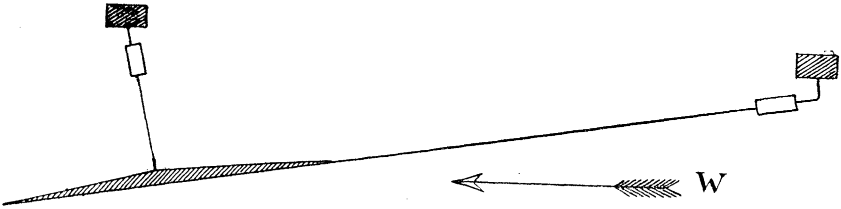


FIG. 1.

To operate this device, a time of calm air is chosen, and the plane is pulled back to any desired angle, say 45°, the normal scale fastened in position, and the weight indications of each scale noted. When wind arises, rotate the platform to face it, so that the plane will stand squarely across its direction. This is not done to expose the plane to any particular direction of wind, but to get all the resistance possible out of it. Then observe the scales to see what effect wind has on the normal and parallel gravity stresses. Any perceptible breeze will be shown by the normal scale, which will indicate less and less weight as wind increases. If the air moves with sufficient force, all weight will be taken from the normal scale, the wire may be cut, and the plane will rest on the air pressure beneath its surface, in which event pressure is substituted for tension on the normal line, otherwise the stress being unchanged, either in direction or magnitude.

If the plane be suspended at the soaring angle of 5°, and wind is strong enough to lift it to that angle, all tension will be taken from the normal scale, the plane resting on air pressure as at the 45° inclination, and so on through all degrees of the arc.

During all this time the parallel scales indicate the weight recorded by them at the various angles in calm air, so that they are not influenced by wind in the least degree, however great its force might be.

If at any angle of obliquity the plane be held by a wire from each corner, perpendicular to it, and fastened to the platform, no force of wind will vary the parallel scales, the tension of the four wires holding the entire wind resistance, however great, In short, there is no way to get wind to affect the parallel scales. If variation in them occurs, it shows at once some error in the experiment, either the wires being out of adjustment, or some warpage of plane or other disturbance having taken place.

The rotating arms for trying this experiment in calm air are 60 feet radius, their ends describing a circle of 120 feet diameter. The plane is hung under the arm, and all the conditions of the other experiment complied with. No change could be noted in the results, excepting that motions of plane were made with greater smoothness, on account of greater steadiness in artificial wind. By no means could air resistance be brought to bear on the parallel component of gravity. It acted the same in wind as in calm air, undisturbed by atmospheric resistance.

Before anything is inferred from these experiments it will be best to state the facts of the case. So completely subversive of the usual conceptions of the action of air on surfaces is this trial that it seems imperative to get the facts right before attempting to range them in the order of mechanical sequence.

For convenience, I will number a few of the conspicuous ones.

1. The scales, being marked in half pounds, do not register

small fractions of force, so that if there be friction down the plane caused by slipping air, such resistance would act on the parallel scales, but, being of small magnitude, could not be read from the index.

2. Neither the cross-arm in wind, nor the rotating arm in calm air, holds the plane against the air. They simply neutralize the parallel factor of gravity, and prevent its acting upon the plane.

3. The normal gravity component does work upon the air by disturbing it in various ways, such as changing its motion, and condensing it, and it is the only fraction of weight that meets with atmospheric resistance, if we neglect the unknown elements of friction.

4. The experiments are in obedience to the law of normal resistance of fluids to surfaces compressing them.

5. There is no resistance to the plane on the line of motion of either plane or air. Even the hypothetical friction is not on such line.

6. Wind or calm air produce identical results ; the only requirement being that air and plane shall meet, motion of either, related to the earth, being indifferent.

The consequences flowing from the above are many and important, and in the briefest manner I will notice those which seem to demand the earnest attention of every student of nature, however abhorrent they may be to text-book devotees.

It is obvious that the wires of the experiment, when the plane is adjusted to any obliquity in calm air, resolves weight in the same way that an ordinary inclined plane would if the latter were rough, the stresses being of the nature of pressure instead of tension.

Then we have in the mathematical formula of inclined planes without friction what also applies to oblique atmospheric resistance. For when the plane of the experiment, held by the wires, is submitted to air pressure, the shape, size, and obliquity of that plane determines the shape, size, and obliquity of the plane of air pressure beneath it, which plane being destitute of friction the component along it must be neutralized, as is done by the parallel wires, to preserve stability; otherwise, the experimental plane would slip down the air plane.

It follows that atmospheric resistance is a purely static feature in all cases; as completely so as a rigid inclined plane, resolving all forces impinging upon it. This becomes still more evident when we see that it is the experimental plane that determines the direction of air resistance, and not the direction in which plane and air meet. If air moved vertically upwards, or from the rear, or from any other direction, against the lower surface, the direction of resistance would be unchanged, and the experiment equally effective. It was not to employ horizontal wind that the experiment was arranged, but to parallel the case with a soaring bird, the working force of which is gravity.

Magnitude of resistance would vary, with the same wind, as its direction approached or receded from the normal line, but, as will be shown farther on, magnitude is unimportant, direction being the vital matter.

If the experimental plane were supposed to be of the same specific gravity as the air it displaces, and some other force used to hold the plane against, or drive it upon air, the same result would follow. This force would be resolved, as gravity is resolved, by the air plane.

The enormous error of the mechanical schools in estimating resistance of air to oblique surfaces is now conspicuous. This error has the sanction of the great name of Newton, and stands squarely across the pathway leading to artificial air navigation, setting up scarecrows along every avenue to success.

But it is consoling to know that no man, not even a Newton, can diagram a force into nature that was not there before the diagram was made.

The entire nature of air resistance is misconceived. The case is a curious one of *bouleversement.* The activities are turned upside down. Instead of the surface resolving the resistance, it is the resistance that resolves whatever forces drive the surface upon it. I have examined over a hundred text-books of mechanical teaching, and have found no exception to the prevalence of this error. They all get resistance on the line in which plane and air meet. They do not all go about it in the same way, but in the end that is where they locate it. So far as I can determine, the error is on the increase, the later authorities being more emphatically astray than the earlier ones. The last utterance that I have seen is contained in a lecture delivered to the students of Sibly College, Cornell University, in May, 1890, by O. Chanute, C.E. On pages 28 and 29 of the published paper the error comes out glaringly. In speaking of M. Drzewieki's work on Duchemin's formula, he says: "Next he calculates the horizontal components of the normal pressure, this being the resistance to the advancement of the plane." His entire exposition is saturated with the blunder, for no horizontal resistance exists. Mr. S. P. Langley, in his recent submission of experiments and suggestions in aërodynamics, entertains the same delusion in its full force, otherwise he seems notably free from a priori bias.

But my thanks are due to some unknown friend who has just sent me a copy of *Science*, dated May 1st, 1891, in which I find marked a letter to the editor on "Flying Machines," by H. A. Hazen. The writer is wholly unknown to me; but I infer that he is neither a "crank" nor a dabbler in science, but a well-grounded expert of wholly intelligent attainments. Without presuming to defend Mr. Langley in the remotest manner, I am justified in holding that Hazen's statements are accepted by the mechanical schools, and I herewith call attention to the utterly erroneous nature of such teaching by contrast to the following facts.

1. A bird does support itself in soaring flight by going fast, and in no other way.

2. There is no evidence that a bird in the act of soaring ever remained stationary in still air for an instant; and whether air is hurled against bird or bird against air, the result is the same; meeting in opposition of bird and air is required by the very nature of soaring flight.

3. "Solution of the problem" is unchanged by "great velocity."

4. As parallel motion on the upward slant is what gives "velocity" to the bird, and as atmospheric friction is the only

resistance to such translation, speed of flight is determined by a force which may, for all practical purposes, be left wholly out of the account.

5. "As a matter of fact," the statement that "it would be much easier to go slow than fast" is a burlesque.

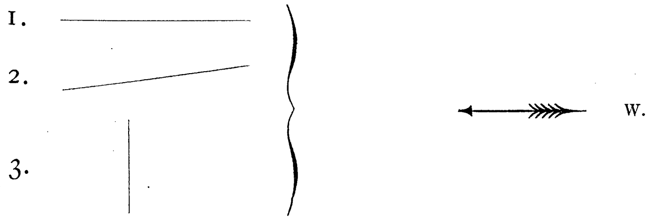
6. Resistance of air at one mile or one hundred miles per hour is practically the same.

So far as I can see, the paraphrased arguments of LeConte do not touch the problem of soaring flight in any way, but all the errors of the mechanical schools are evidently adopted by him.

But here is by no means the end of this catena of difficulty.

There are three ways, shown in the subjoined diagram, in which a surface and air can meet.

1. Parallel to the surface.
2. Obliquely to the surface.
3. Normal to the surface.



The first meets with frictional resistance.

The second with both friction and pressure.

The third with pressure resistance only.

The direction of the first and third resistance is in the line on which plane and air meet, there being a single stress on that line. The directions of the second resistances are both parallel, and normal to the plane, there being two stresses perpendicular to each other, and no stress on the line in which plane and air meet.

It directly follows that direction of motion of the second case is a resultant, composed of two velocities, one on the line of frictional, the other on the line of pressure resistance, the plane being a body subject to two forces, neither of which are in the line of motion.

No single force, however great, could drive a plane obliquely through air. There must of necessity be not less than two stresses, derived either from the application of two forces, or the resolution into two components of one.

I need go no further in this direction, but will add a few words regarding my work during the past year and a half, in the way of direct flight.

It is sufficiently obvious that a force of about two pounds' constant pressure applied to the plane, either in wind or calm air, in the above experiments, to take the place of the cross-arm and rotating arm, neutralizing the parallel component of gravity, would, if obtained from the constant flow of twenty-seven pounds pressure escaping from beneath the surface, produce a true soaring plane in calm and wind.

A smooth plane has no tendency to throw two pounds of this twenty-seven pounds (over 90°) against the obstructive component.

The true problem of flight consists in so manipulating the surface as to perform this function. I have hitherto taken the wing of a soaring bird as a model, and have had unexpected and most gratifying success.

I can produce true soaring flight in natural wind with a plane exceeding two pounds to a square foot of surface whenever I wish to do so and can obtain wind strong enough for the purpose. During the above-mentioned period of time I have made about fifty planes of various shapes and sizes, and from 25 to 400 pounds in weight. These planes are not set free in wind, but used as in the experimental cases above, with rigid rods in place of the parallel wires. These rods run in large rings and have a cross head at their outer ends, allowing the plane to run to the front until its edge rests against the rings. In the best trials the parallel component is neutralized at 10° from horizontal, far exceeding my expectations derived from observations of the birds; their angle of obliquity being rarely over 5°.

On a few occasions these planes accidentally escaped me in time of highest wind, and were ruined at once for all purposes excepting fire-wood; in each case being a loss of two or three months' work, and playing havoc with my finances. One that I valued particularly plunged to the front in a violent blast of wind with force sufficient to tear out the rings. It rose into the air gradually higher and higher, until an elevation of at least 3,000 feet was attained, when some part of the device giving away it lost equilibrium, and plunged through the air, striking the earth about two-and-a-half miles from the starting point, and 1000 feet higher than that locality. Another mile would have carried it to the summit of the Flat Top Mountains. It was in the air about three hours, and I walked beneath it during its flight. Its course was directly against the highest wind I have experienced during my residence here. At times it did not progress, but went higher. It weighed one hundred and ten pounds, and had been well balanced for experimenting on surface manipulation. There was no lesson taught in this flight, the birds having been doing the same thing for a long time. It was an interesting spectacle to look at; so is a large bird in the same act. I presume Mr. Darwin's provisional solution would apply to this plane as well as to the condors, but I am trying to explain the actual mechanical activity of both.

The best effects produced were with a plane of 400 pounds weight and eighty square feet of surface. In a wind that would be rightly termed a gale, arising about midnight, this plane was thrown to about 7° from horizontal. It ran to the front against the rings at 10°, where the entire parallel component was neutralized, and at 7° it hugged the rings with a force that required a backward pull of fifteen pounds to detach it.

This plane would make a splendid air navigator, and I would have no hesitation in trusting myself to it when steering, equilibrium, and alighting or stopping items had been worked out. I mean to say that it would navigate wind. I am now just entering on a course of experiments in calm air.

The front ledge is an important factor in steadiness, but the rear curve I have entirely abandoned, surface manipulation being depended upon to produce the parallel thrust. My judgment is that I have succeeded in separating the mechanical devices of a bird's wing which produce flight from those serving other life purposes of the animal. It has been an arduous task. At the close of experimenting in this line I hit upon a method not exhibited by the birds, which promises best results, but which waits further developments.

Let us suppose a soaring bird of twenty-seven pounds weight, with stretched wings on an angle of 5° from horizontal, translating itself in calm air, or stationary when related to the earth in wind. Suppose, further, the initial impulse to have been made so that its motion is uniform.

Then its weight is resolved into a normal and parallel component by the air plane of pressure beneath it. The normal component does work by driving the air out of place, thereby changing its motion. The parallel component acts upon the bird, tending to drive it on the downward slant, backwards. The air in being condensed reacts in all directions, and reaction towards the front being resisted by the surface manipulations, the bird is driven against friction and the small component, on the upward slant, and, completing the diagram of velocities, the result is horizontal flight.

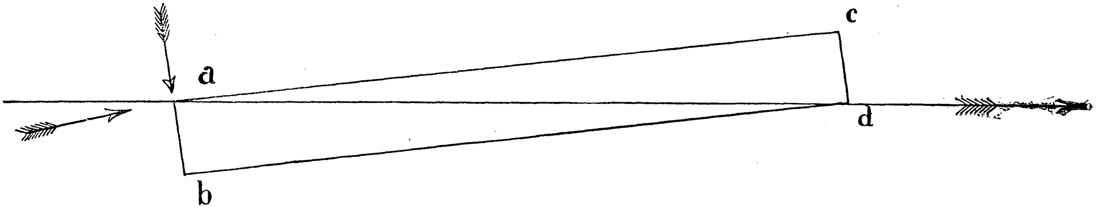


FIG. 2.

If the parallel factor be supposed out of the way by neutralization arising from surface manipulation, and the air to be calm, then the normal factor would drive the plane against air pressure from *a* to *b* in any given unit of time, say one second.

Simultaneously with this motion a small excess of parallel force over that required to balance the parallel factor—say one-half pound constant pressure—would drive the plane from *a* to *c*, against friction, in which case motion would occur on *a d*, the resulting line of horizontal flight.

I have said that direction, and not magnitude of force, was the vital point in the soaring activity. This fact must now be quite plain. Magnitude of force depends on weight of plane, and on that alone. The gravity stress existing between the plane and the earth's center is the only conceivable force in action, and air will meet any demand made upon it by the normal factor of this force, against which it is a reaction. This factor is determined by the angle of obliquity of plane in each case, and the work done upon the air goes on independently of the parallel motion of the plane on the upward slant, which alone gives a soaring movement. It is obvious that whether wind should move from the zenith downwards, or from the earth vertically upwards, or horizontally, or from any angle of obliquity whatever, the soaring activity is not affected. That goes on as it does in calm air. Motion of plane as related to the earth would of course vary with wind, if inclination remained the same, but the soaring action, considered by itself, is absolutely independent of wind,—meaning by that word motion of air as related to the earth.

I had prepared specimen feathers from the wings of various birds during the past twenty-five years, intending to prepare a paper for publication on the subject of surface manipulation, which I hold to be the most curious and interesting feature about a bird, yet almost paralleled by the wonder that it has hitherto escaped notice. But we have a rat, if it be a rat, that is endowed with a peculiar moral nature. With it, exchange is no robbery. A nest of them inhabited the building in which I kept my specimens, and they bartered what I laid claim to for an indescribable lot of miscellaneous rubbish of no earthly use to me. Their views and mine were very different. They had cut the feathers into small bits and mixed them with dirt, and stowed them away in all sorts of holes and corners. I shut a cat in the room for some days, which caused the rodents to vanish, but my feathers were ruined.

If you will take a primary wing feather of any large bird,—say a wild goose, or especially a frigate bird,—and cut squarely across the ribs, and examine the divided part endwise with a magnifying glass of low power, you will see nature's plan of surface manipulation to get the forward thrust against the small component of weight and air friction. Cut on *b c*, and examine

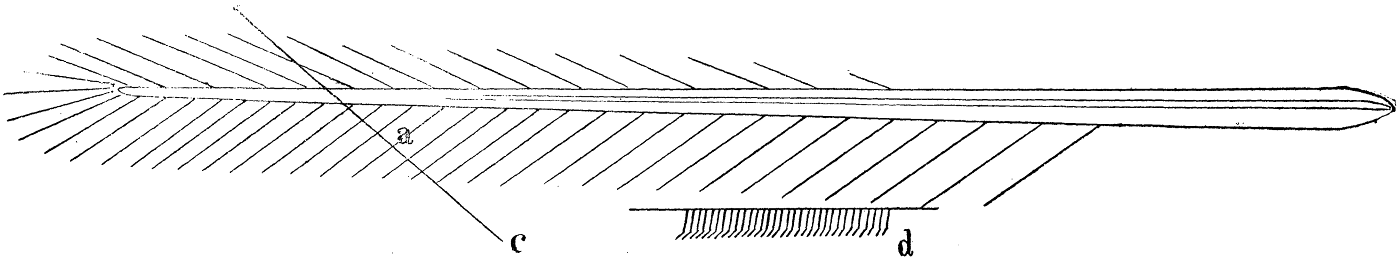


FIG. 3.

the cut ends of the ribs along *a*. You will see something like *d*. If we suppose an unpressed small portion of air to be represented by a small circle o, and the same air when pressed, by a flat disk ⬭, and then mesh this disk with the sort of surface made by the manipulation, the nature of the front thrust will be made thinkable. I enlarge it below. That part of the air particle to

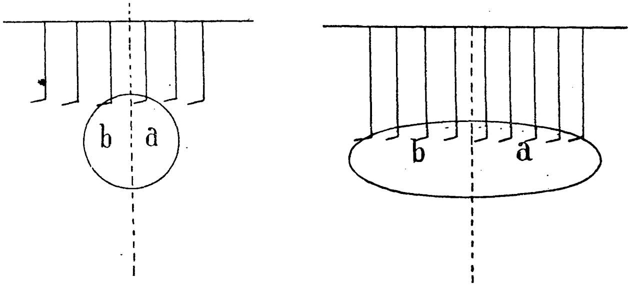


FIG 4.

the rear of the dotted line as *b* slips easily over the ribs, while the front part, *a*, engages with them and tends to carry them to the front. I have worked out all this artificially with excellent results, and can give you a paper upon it if a large part of the actual size and shape of the ribs in different birds is left to memory, as the rats have destroyed my samples.